GIS-Based Soil Properties Analysis for Sustainable Agriculture in Bani Waleed (Libya)

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Abstract— *This paper presents an study Soil Properties analysis for sustainable agriculture by GIS through 15 soil samples chemical characterization conducts to soil numerical classification and crops soil suitability that has the advantage to guide the practices of soil management is as follows: Soil Salinity: The results of electrical conductivity indicated that the studied soils were generally positioned into the very saline class that had an area of (3847.96 ha) representing (79.50 %). The soils assembled into five classes; non-saline (198.5 ha) and it is suitable for most crops, moderately saline (385.75ha), where crops salt-tolerant crops give yield with marginal reduction. Finally, strong saline (112.00 ha) that it is suitable just for high salt-tolerant crops but also with yield reduction. Soil Sodic: the non-sodic soil class occupied the majority of the studied area with 96.8 % (4689.18 ha). The sodic soil had only (151.27 ha) 13.12 %. calcium carbonate to moderately calcareous soil (2317.93 ha) 47.89% and calcareous soil (2522.51 ha)52.11%. Crops soil suitability (Wheat): (S1), (S2) and (NS2) It is as follows (4000.78ha) 82.65 %, 114.37ha 2.36 %, and 725.30ha 14.98% of the studied area, respectively. (Tomato): is as follows: (4190.85 ha) 86.58 % of the study area is highly suitable (S1) and (NS2) (649.61ha) 13.42 % is unsuitable represent respectively. (Olive): The majority of the study area 4081.04 ha (84.31 %) was classified as highly suitable soils (S1), potentially suitable class (NS1) is about 236.61ha (4.89 %) and unsuitable class (NS2) is about (522.81ha) 10.80 % respectively. Soil Management and Crops tolerance for soil parameters The GIS-ESP soil map divided the studied area into three categories of ESP tolerance crops soil; Extremely sensitive ESP crop (4164.65 ha), sensitive ESP crop (594.13 ha) and moderately tolerant crop (81.67 ha). The GIS-CaCO3 soil map divided the studied area into two categories of CaCO3 tolerance crops soil; Crops that tolerate a certain (1924.92 ha) and Crops which support high (2915.54 ha). EC tolerance crops soil; Sensitive (3835.38 ha), moderately (224.28ha), highly (650.86 ha) and very highly (129.93ha).*

Keywords— Sustainable Agriculture, GIS, Soil Suitability and Tolerant Crops.

I. INTRODUCTION

The main soil problems of Libyan agriculture are erosion and salinity. New tasks that have become a priority in the past few years are the degradation of counter-land resources and the improvement of poor land management practices. About 1.75 million square kilometers in range. More than 95 percent of the country is desert. The arable areas cover an estimated 3.8 million hectares, just over 2 percent of the total area. The majority of cultivated land and pastures [1].Saline soils in Libya cover about 52%, which is as follows: 12% in the north, 16.5% in the west and 23.4% in central Libya. [2]. Water and wind erosion are also prevalent in western Libya (Jafara Plain and Jabal Nafusa) as a result of agricultural operations, and in the Wattiyah region and the southwestern Jafara Plain[3].Agricultural soils are of great importance for increasing crop production, protecting water and air, reducing greenhouse gas emissions, and maintaining natural biodiversity and food safety[4].The increase in the world's population is putting increasing pressure on natural resources [5,6]. This behavior of exploitation leads to multiple environmental problems of land and water [7], Appropriate land-use and management strategies must be needed to reduce the magnitude of negative human impacts [8,9]. Agricultural processes have an impact on the physical, chemical and biological properties of soils [10], resulting in environmental problems such as soil degradation [11. Sustainable land management requires reliable information on the spatial distribution of soil characteristics that affect both the landscape process and services [12,13].In the traditional soil study, soil properties are recorded in representative locations throughout the entire mapping unit, which are chosen using both physiological and geophysical methods. Although soil surveyors are well aware of the spatial variation of soil properties, traditionally prepared soil maps do not reflect them because the soil units are limited in boundaries [14]. Nature the soil properties are highly variable spatially [15].The traditional method of soil analysis and hence becoming expensive. Soil problems in Libya are: (1) improper agricultural operations, such as not using deep tillage, (II) overgrazing. (Third) the conversion of rangelands to croplands in marginal areas where rainfall is not sufficient to support crops in the long run; and (iv) urban and rural expansion at the expense of arable land in Libya, large areas of soil have deteriorated due to profound irrigation with saline groundwater. The main target aim of this study was to link the GIS- maps of soil to sustainable agriculture for soil.

II. MATERIALS AND METHODS

The study area is situated between coordinates (455726.38E) and (3495270.93N). Fig (1) show the study area is located in the northwest of Libya in the Bani Waleed region. The study area is extracted in WADY SEOFJEEN alongside to the Southwest of Tripoli. It is bounded to the north Mediterranean Sea. study area covers about 4840.45 Hectare Fig (2). The study was elaborated through four stages. The first stage was consecrated to build-up spatial database by processing of topographic maps; (a) collection, digitizing and mosaicking of the topographic maps (b) mosaicking clipping the topographic maps excerpt the studied area), by using the software of geographic information system (ArcGIS 10.3). The second stage was consecrated to the fieldwork to collect the sample's soil at depth (0-80 cm). Laboratory work represented the third which included that chemical characterization of soil samples. fig (1).

Building-up Spatial Database (topographic maps processing):

Building-up Spatial Database was built through the processes of maps collection, digitizing, mosaicking and Clipping. were digitized by Arc-GIS10.3 software. The coordinate was converted from the geographic coordinates (Lat.–Long.) system to Universal Transverse Mercator (UTM) coordinates system (Easting–Northing). The topographic map sheets, covering the surrounding region, were merged together in one map to compose mosaic map. The mosaic was clipped to extract the study area that has the coordinates (455726.38E and 3495270.93N) (the upper left corner), fig (1).

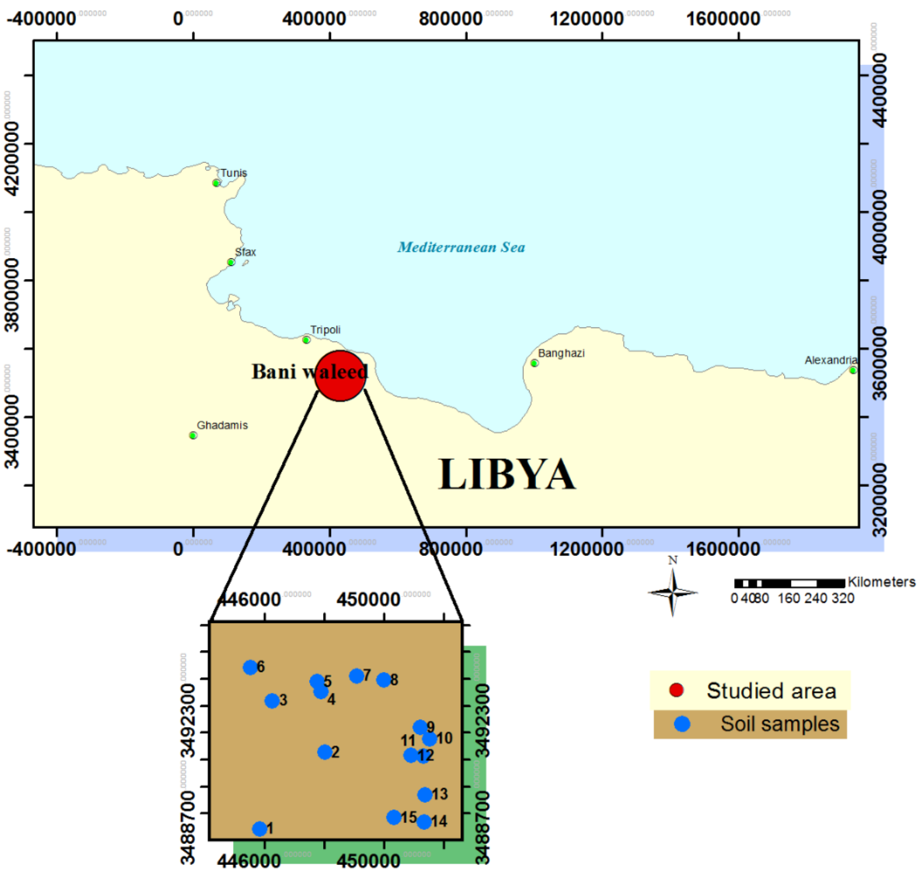

FIGURE 1. Location of studied area

2.1 Sampling and Analysis of Soil Samples

2.1.1 Soil Sampling

Fifteen soil samples depth (0-80cm) were collected to represent the root zone of the studied area. The samples were aired air dried and crushed pass through 2 mm sieve to elaborate the different analysis. Soil sampling was carried out using the random nested soil sampling design that covered an area Fig (2). Soil samples locations were determined by GPS.

2.1.2 Soils Physical and Chemical Characterization:

- **Soil Physical Analysis**

Texture was determined using sieves and Hydrometer method [16].

- **Soil Chemical Analysis**

Salinity was measured at in the soil paste extract and pH of 1:2.5 soil suspension by EC meter and P^H[17], Sodium Absorption Ration (SAR) was calculated from Ca, Mg, and Na soluble concentrations, soil organic matter content (OM%) was determined by Walkely & Black method [17] and CaCO3% was determined using the pressure calcimeter method [17].

2.2 Land suitability evaluation

Rated Land suitability classes (Table 1) [18,19,20].The majority of both limitation and parametric methods use the FAO (1976) framework for land suitability classification. In this framework, lands are classified into five classes ranging from highly suitable to permanently not suitable considering the existing limitations for a specific use (FAO 1976).Land suitability analysis is a very important technique for agricultural activities to deciding future cropping pattern, planning and activities. It is determining appropriate crops for a specific piece of land according to its characteristics [21,22] and allows identification of the limiting factors for the crop cultivation [23].

TABLE 1
LAND SUITABILITY CLASSES

Class	Description	Rating (%)
S1	Highly suitable	100 - 80
S2	Moderately suitable	80 - 60
S3	Marginally suitable	60 – 40
S4	Conditionally suitable	40 - 20
NS1	Potentially suitable	20 - 10
NS2	Actually unsuitable	< 10

TABLE 2
REACTION CLASS TERMS AND THEIR RANGES IN EC, ESP, CACO3, OM AND PH [24]

Rating	Class
EC(dS/m)	
Nonsaline	< 2
Very slightly saline	2 to < 4
Slightly saline	4 to < 8
Moderately saline	8 to < 16
Strongly saline	≥ 16
ESP%	
Non- Sodic	<15
Sodic	>15
CaCO3 %	CaCO3 %
Non Calcareous	<15
Moderately Calcareous	15-20
Calcareous	>20
OM%	
very low	<1
low	1–2.5
medium	2.5–5.0
high	5.0–10.0
very high	>10.0
PH	
strongly acidic	<5.5
moderately acidic	5.5–6.2
neutral	6.2–7.0
moderately alkaline	7.0–7.8
strongly alkaline	>7.8

Calcium carbonate - Calcium (Ca) is a common component in most soils. It is generally the most important cation (between 65 and 80 %) of the exchange complex, and most plants require it. It is only when too much (more than 5 %) free lime is present in the root zone that it affects some plants. Hence, this is not toxicity in itself but a suboptimal concentration of free calcium in the root zone due to either a natural weathering process of the underlying (carbonaceous) rock, or an accumulation of calcium compounds from wind or water deposits [25].

TABLE 3
CROPS TOLERANCE AND $CaCO_3$ SOIL PARAMETERS

Crops which support high amounts of free $CaCO_3$(>25%)	Crops that tolerate a certain amounts of free $CaCO_3$(5-25%)	Crops that are sensitive to $CaCO_3$(<25%)
Dates	Barley	Citrus tress
Olives	Cotton	Bananas
figs	Maize	Potato
Alfalfa	Millets	Cassava
wheat	Rice	Tea
--	Grapes	Lupins

III. RESULTS AND DISCUSSION

3.1 Physical and chemical of the soil samples:

Fifteen soils samples (0-80 cm) were taken from the clipped agricultural area. Soils locations were determined by their UTM coordinates table (4), fig (2). The results of particle size distribution classified the collected soil samples into four textural classes table (5): Silty loam (samples 1 and 14) Sandy clay loam (samples 2and 3) Sandy loam (samples 4,5,6,7,8,10,11 and 13), loam (samples 9,12 and 15).

TABLE 4
UTM COORDINATES OF SOIL SAMPLES

No (Sam)	Soil Samples coordinates (UTM)	
	Easting	Northing
1	445854.144	3488195.231
2	448034.696	3490781.467
3	446209.118	3492404.203
4	447907.92	3492759.177
5	447755.788	3493114.15
6	445524.526	3493570.545
7	449074.262	3493291.637
8	449987.051	3493139.506
9	451204.103	3491592.835
10	451508.366	3491212.506
11	451330.879	3490578.625
12	450925.195	3490654.69
13	451381.59	3489285.507
14	451356.235	3488423.428
15	450342.024	3488550.204

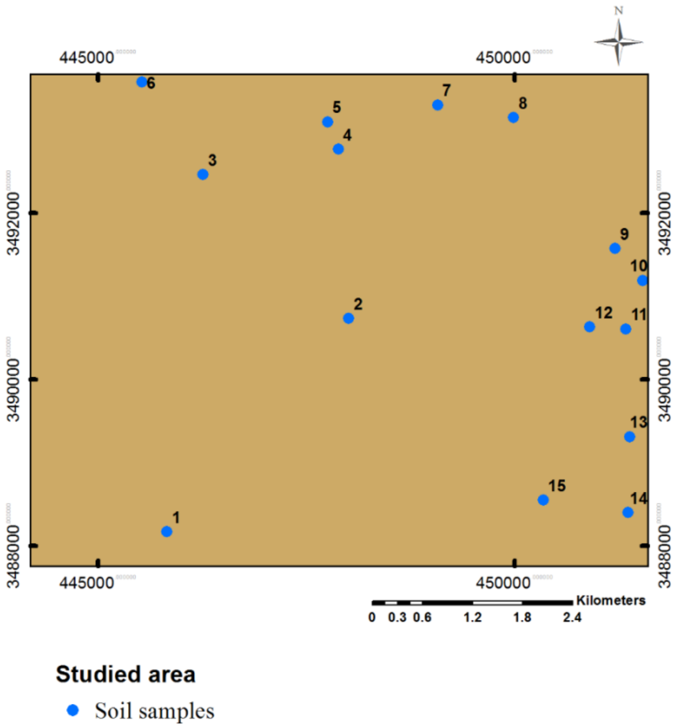

FIGURE 2: Studied area and soil samples locations

3.2 Soil Chemical Characteristic

This tables (2 and 5) showed that the samples were distributed into five pH, salinity and OM classes and into two ESP classes, and into three CaCO3 classes with summarizes some soil chemical characteristics of soil samples. It is as follows: (pH) as criterion, classified the soil samples: The high pH values obviously indicated that the soils are strongly alkaline ones. The maximal pH value was 8to represent strongly alkaline soil that had pH values > 7.8 (sample 9 and 15). (saline) as criterion, classified the soil samples: Nonsaline soils: (samples 1,2,3 and 14),Very slightly saline (samples 4,10,11 and 13), Slightly saline soils : (samples 9,12 and 15), Strongly saline soils : (samples 5,6,7 and 8 (OM) as criterion, classified the soil samples: very low:(samples 2,3,4,5,6,7,8,9,10,11,12,13,14 and 15), low sample 1). (ESP) as criterion, classified the soil samples: Non- Sodic:(samples 1,2,3,4,5,6,8,10,11,13 and 14), Sodic: (samples 7,9,12 and 15). (CaCO3) as criterion, classified the soil samples: Moderately Calcareous: (samples 4,8,10,11,13 and 15), Calcareous: (samples 1,2,3,5,6,7,9,12 and 14).

TABLE 5
PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL SAMPLES

Samples No	p^H	EC dS/m	Soluble Ions (meq / L)						ESP %	$CaCO_3$(%)	OM (%)	Textural Class
			Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}				
1	7.5	1.4	12	13	8	5.1	18	16.6	8	41	1.16	Silty loam
2	7.8	1	2	2.2	6	0.6	5	3	3.6	20	0.5	Sandy clay loam
3	7.8	1	2.6	2.1	5.9	0.6	5	5.3	3.7	20	0.5	Sandy clay loam
4	7.5	2	10	4.8	3	1.5	10	5.2	6	16.3	0.5	Sandy loam
5	7.6	17	55	32	77	1.8	168	11	14	30	0.5	Sandy loam
6	7.6	17	55.8	33	76	1.7	169	10.4	13.8	30	0.9	Sandy loam
7	7.7	46	140	71	209	2	394	19.6	25	28	0.9	Sandy loam
8	7.6	17	56	33	78	1.8	398	12	14	16	0.6	Sandy loam
9	8	7	35	27	37	0.9	40	24.4	19	25	0.7	loam
10	7.5	2	10	5	4	1.5	5.3	5.6	7	16.2	1.5	Sandy loam
11	7.5	2	10.5	4.9	3.5	1.7	5	5	6	16	0.5	Sandy loam
12	8	7	35.8	26.8	38	1.9	39.8	24	19	25	0.6	loam
13	7.5	2	11	4.5	3	0.9	10	5	6.5	15.5	0.8	Sandy loam
14	7.5	1.4	12	13.5	8	5	17	15	8.5	42	0.4	Silty loam
15	8	7	35	27.5	37	0.8	41	24	19	17	0.7	loam

3.3 Soil Univariate Chemical Classification for sustainable agriculture

The studied soils were chemically classified basing separately on the thresholds of pH, EC, ESP and CaCO3 that are the most effective factors on soil production: Soil Salinity: The results of electrical conductivity indicated that the studied soils were generally positioned into the very saline class that had an area of (3847.96 ha) representing (79.50 %). The soils assembled into five classes; nonsaline (198.5 ha) and it is suitable for most crops, moderately saline (385.75ha), where crops salt-tolerant crops give yield with marginal reduction. Finally, strong saline (112.00 ha) that it is suitable just for high salt-tolerant crops but also with yield reduction (Table 6 and Figure 3).

TABLE 6
UNIVARIATE SOIL CHEMICAL CLASSIFICATION

Soil chemical Criteria	Thresholds	Soil Chemical Classes	Soil chemical Criteria	Thresholds	Soil Chemical Classes	Area(ha)
Exchangeable Sodium Percentage (ESP) %	< 15	Non-Sodic	Electrical Conductivity (EC) ds/m	< 2	Nonsaline	198.5
				2 to < 4	Very slightly saline	3847.96
	>15	Non-Sodic		4 to < 8	Slightly saline	296.96
				8 to < 16	Moderately saline	385.75
				≥ 16	Strongly saline	112.00
CaCO3	15-20	Moderately Calcareous	Area(ha) 2317.93	CaCO3>20	Calcareous	2522.51

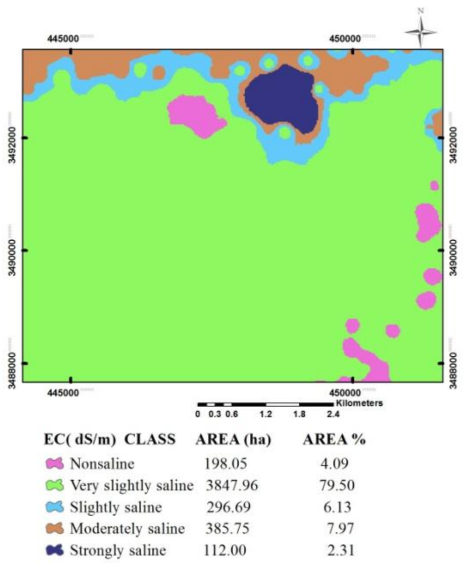

FIGURE 3. EC ds/m

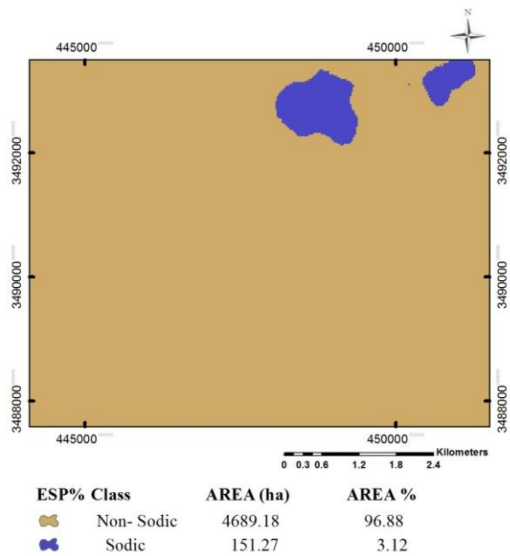

FIGURE 4. Soil ESP %

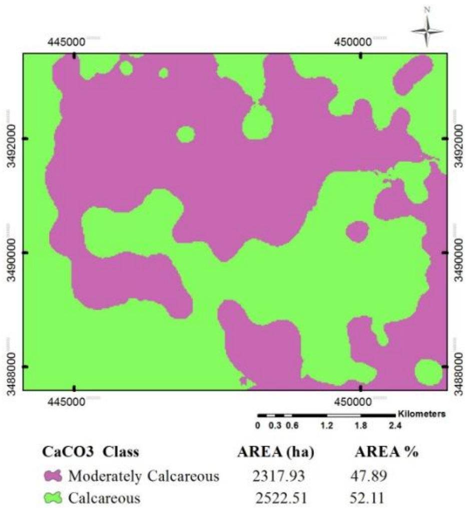

FIGURE 5. CaCO3 %

Soil Sodic: Results showed for (Table 7 and Figure 4). The non-sodic soil class occupied the majority of the studied area with 96.8 % (4689.18 ha). The sodic soil had only (151.27 ha) 13.12 %.

Calcium Carbonate Content: Calcium carbonate of the study area had different forms such as powder, nodules, concretions, and hard layers. Calcium carbonate in calcareous soil gives it one of the important morphological phenomena, which is the surface crust. Results showed for (Table 7 and Figure 5) The study area was to classified into two classes according to the percentage of calcium carbonate to moderately calcareous soil (2317.93 ha) 47.89% and calcareous soil (2522.51 ha) 52.11% .

Land evaluation for Suitable crops:

(Cereals crop Wheat): The data indicated that the studied soil conditionally suitable for wheat crop. The class of conditionally suitable (S1) Highly suitable soils, (S2) low degree of soil suitability and (NS2) unsuitable represent It is as follows 4000.78 ha 82.65 %, 114.37 ha 2.36 %, and 725.30 ha 14.98% of the studied area, respectively (Table 1 and Figure 6).

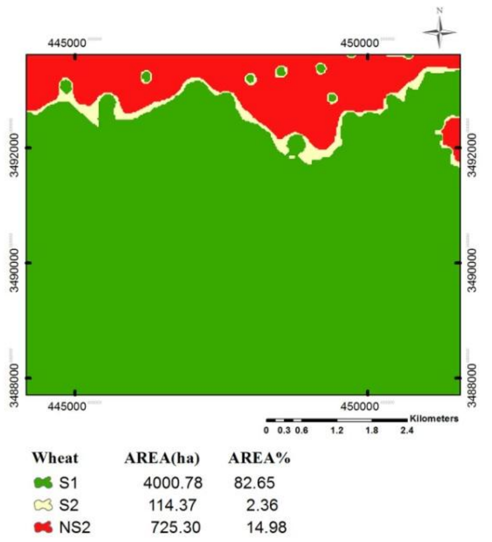

FIGURE 6. Soil suitability classes for wheat crop

Vegetables (Tomato): The results of this study are suitable for tomato plantation is as follows: 4190.85 ha 86.58 % of the study area is highly suitable (S1) and (NS2) 649.61 ha 13.42 % is unsuitable represent respectively (Table 1 and Figure 7).

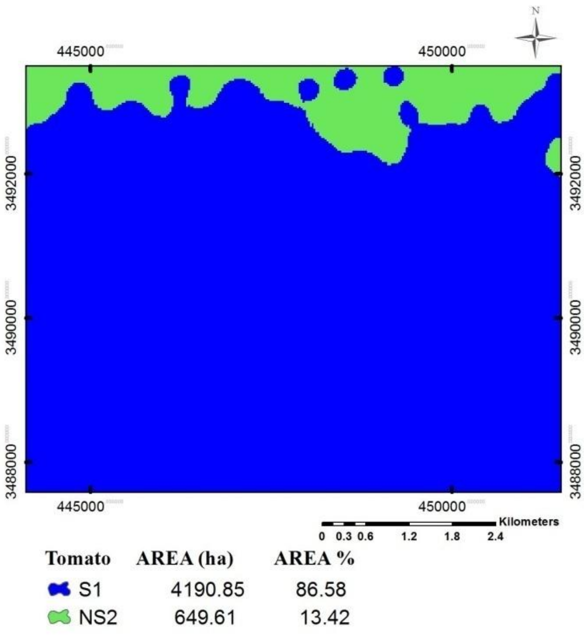

FIGURE 7. Soil suitability classes for tomato crop

Perennial crop (Olive): The results of this study showed that the region is meanly suitable for olive plantation (Table 1and Figure 8). The majority of the study area 4081.04 ha (84.31 %) was classified as highly suitable soils (S1), potentially suitable class (NS1) is about 236.61ha (4.89 %) and actually unsuitable class (NS2) is about 522.81ha (10.80 %) respectively.

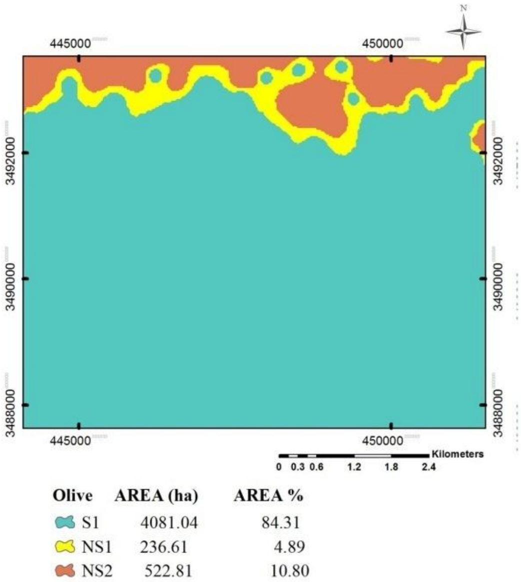

FIGURE 8. Soil suitability classes for olive crop

Soil Management and Crops tolerance for soil parameters (Basing on soil chemical univariate classification): Soil ESP Problem: Selected to reduce the problem of soil ESP (Table 8) .GIS-ESP soil classification was elaborated by assignment ESP thresholds of tolerant crop range (Table 8) to GIS-ESP soil map (Figure 9). The GIS-ESP soil map divided the studied area into three categories of ESP tolerance crops soil; extremely sensitive ESP crop (4164.65ha), sensitive ESP crop (594.13 ha) and moderately tolerant crop (81.67 ha)

Soil CaCO3 Problem: GIS-CaCO3 soil classification was elaborated by assignment CaCO3 thresholds of tolerant crop range (Table3) to the GIS-CaCO3 soil map (Figure 10). The GIS-CaCO3 soil map divided the studied area into two categories of CaCO3 tolerance crops soil; Crops that tolerate a certain (1924.92 ha) and Crops which support high (2915.54 ha).

Soil EC Problem: EC as shown in figure 11. This map involved four classes of EC tolerance crops soil range (Table7): Sensitive (3835.38 ha), moderately (224.28ha), highly (650.86 ha) and very highly (129.93ha).

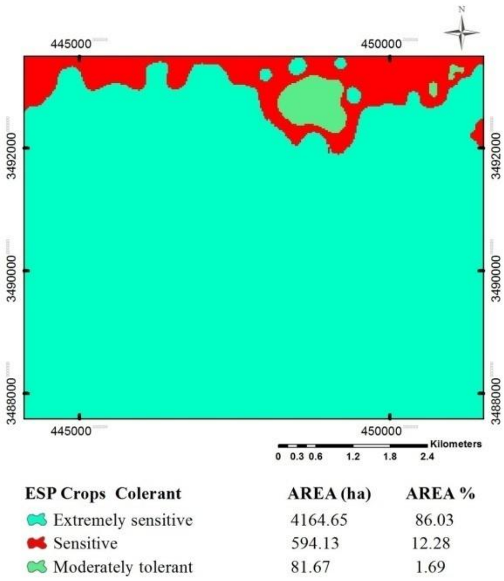

FIGURE 9. ESP Crops Tolerant

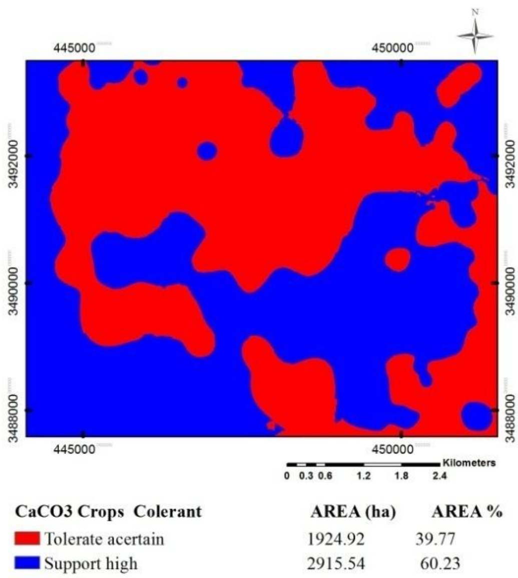

FIGURE 10. CaCO3 Crops Tolerant

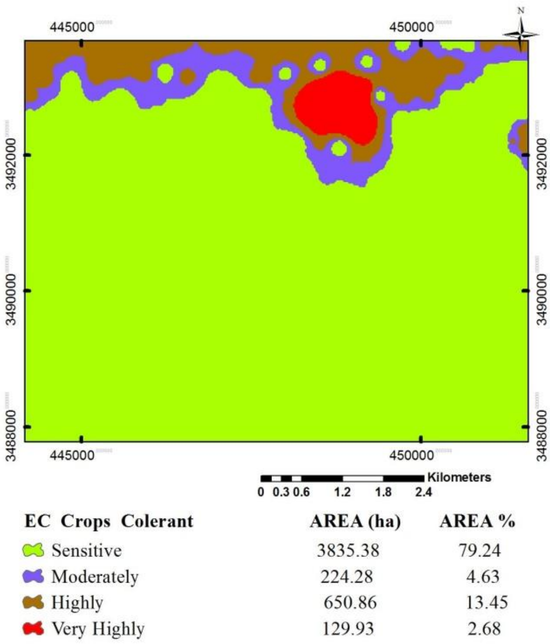

FIGURE 11. EC Crops Tolerant

TABLE 7
CROPS TOLERANCE AND EC SOIL PARAMETERS

Mapping Unit	EC Crop Tolerance	EC (dS/m) tolerant crop range
1	Sensitive EC crops: (Field crops) Sunflower, Soybean, Faba bean, Lins, (Vegetable crops) Sweet corn, Lettuce, Onion, Eggplant, Carrot, (Fruit crops) Date, Olive, Peach , Orange, Grapes	1 - 4
2	Moderately EC tolerant crops: only field crops Barley, Cotton, Sugar beet, Grain sorghum, Wheat	4-8
3	EC tolerant crops: No crops have 0 % yield reduction	8-16
4	Highly EC tolerant crops: No crops have 0 % yield reduction	16-32

TABLE 8
SELECTION ESP CROPS TOLERANT

Soil Chemical Classes	ESP Crop Tolerance	ESP (dS/m) tolerant crop range
Non-Sodic	Extremely sensitive ESP Crops (ESP = 2-10) ; Nuts , Citrus, Avocado Sensitive ESP crops (ESP = 10-20); Beans Moderately tolerant (ESP = 20-40); Clover	<15
Sodic	Tolerant crops (ESP = (40-60) ; Wheat, Cotton , Alfalfa , Barely , Tomato, Beets Most tolerant crops (ESP > 60); Tall wheat grass , Rhodes grass	>15

IV. CONCLUSION

Soil Properties analysis for sustainable agriculture led to soil classification that guide accurately and quantitatively the practices of soil management. Comprehensive analytical approach of soil by GIS evaluation of the processes of soil classification, soil suitability for crop Hence land suitability analysis outputs reliable information related to crop opportunity and reduction; it provides a significant contribution to land use reliably and economically. Farmers can use soil suitability information to choose crops suitable for their soil, as well as an accurate database and guide maps for decision-makers. The suitability of the soil for crops It mainly determines the characteristics of the soil and crop yield, EC, ESP, and CaCO3 crop tolerance. After the limit Or eliminate the factors that limit the soil in the area studied Maybe grown wheat, Olives and tomatoes. Some Selected crops such as olives and Tomatoes It is recommended to grow it in the study area. Most Marginally

suitable land with severe restraint factors Such as EC, ESP, and CaCO3 It is located in the northern upper part of the study area. Through digital maps, the study area where salinity is mostly low, as well as Sodic, calcium carbonate is high, and this indicates that the soil has some obstacles that hinder the agricultural process, While as it is suitable for wheat crop by 82.62%, tomato crop by 86.58% and olive crop by 84.31%. Assignment ESP thresholds of tolerant crop range Extremely sensitive 86.03%, CaCO3 of tolerant crop range 60.23%, EC tolerance crops soil Sensitive 79.24%.

REFERENCES

[1] FAO (2002) Land Resources Information Systems IN The near East Regional workshop Cairo, 3–7 September 2001 Rome.ww.fao.org

[2] Mahmoud, K.B (1995) Libyan Soils. First Edition ed. Tripoli: National Research Scientific Organization.

[3] FAO (2015)| Regional Assessment of Soil Changes in the Near East and North Africa, Status of the World's Soil Resources | Main Report Chapter 13.ww.fao.org

[4] Bremer E and Ellert K (2004) Soil quality indicators: A review with implications for agricultural ecosystems in Alberta; AESA

[5] Santana-Cordero, A.M.; Ariza, E.; Romagosa, F. (2016) Studying the historical evolution of ecosystem services to inform management policies for developed shorelines. Environ. Sci. Policy, 64, 18–29.

[6] Hanh, H.Q.; Azadi, H.; Dogot, T.; Ton, V.D.; Lebailly, P.(2017)Dynamics of Agrarian Systems and Land Use Change in North Vietnam. Land Degrad. Dev., 28, 799–810.

[7] Tengberg, A.; Radstake, F.; Zhang, K.; Dunn, B. (2016) Scaling up of Sustainable Land Management in the Western People's Republic of China: Evaluation of a 10-Year Partnership. Land Degrad. Dev., 27, 134–144.

[8] Lal, R. (2009) .Soils and sustainable agriculture: A review. Agron. Sustain. Dev., 28, 57–64.

[9] Brevik, E.C. The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture 2013, 3, 398–417.

[10] Brevik, E.; Calzolari, C.; Miller, B.; Pereira, P.; Kabala, C.; Baumgartner, A.; Jordán, A. (2016) Historical perspectives and future needs in soil mapping, classification and pedological modelling. Geoderma, 264, 256–274.

[11] Panagos, P.; Borrelli, P.; Poesen, J.; Ballabio, C.; Lugato, E.; Meusburger, K.; Montanarella, L.; Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy, 54, 438–447.

[12] Lin H, Wheeler D, Bell J, Wilding L (2005) Assessment of soil spatial variability at multiple scales. Ecol Model 182:271–290

[13] Shibu M, Leffelaar P, Van Keulen H, Aggarwal P (2006) Quantitative description of Soil organic carbon matter dynamics—a review of approaches with reference to rice-based cropping systems Geoderma 137:1–18.

[14] Heuvelink GBM, Webster R (2001) Modeling soil variation: past, present, and future. Geoderma 100(3–4):269–301

[15] Burrough P (1993) Soil variability: a late 20th century view. Soils Fertil 56:529–562

[16] Kettler, T.A., Doran, J.W. and Gilbert, T.L. (2001) Simplified Method for Soil Particle-Size, In "Determination to Accompany Soil-Quality Analyses", USDA-ARS / UNL Faculty U.S.(849 – 852).

[17] Page, A.L., Miller, R.H. and Keeny, R. (1982) Methods of Soil Analysis. Part2. Chemical and Microbiological Properties, Agron. Monograph No. 9, ASA, Madison, WI, USA.

[18] (FAO, 1976). A framework for land evaluation. Bulletin, 32, FAO, Rome, 72 pp.

[19] Ismail, H.A., E.M. El-Zahaby and M.E. El-Fayoumy. (1994). A modified approach for land evaluation under arid condition. 11. Applications. J. Agric. Set., Mansoura Univ. 19 (10). 3497.

[20] Ismail, H.A., I. Morsy, El-Zahaby, E.M. and El-Nagar, F.S. (2001). A developed expert system for land use planning by coupling land information system and modeling. Alex. J. Agric. Res. 46 (3). 141

[21] Singha, C. and K.C. Swain. (2016). Land suitability evaluation criteria for agricultural crop selection: A review. Agricultural reviews. 37. (2):125-132 Print ISSN: 0253-1496 / Online ISSN: 0976-0539

[22] Pan, G. and J. Pan. 2012. Research in crop land suitability analysis based on GIS, Computer and Computing Technologies in Agriculture. 365: 314–325.

[23] Joerin, F., M. Thériault, and A. Musy.(2001). Using GIS and outranking multicriteria analysis for land-use suitability assessment, International Journal of Geographical Information Science. 15(2): 153-174.https://www.tandfonline.com.

[24] USDA (2017) Soil Survey Manual, handbook no.18 https://www.nrcs.usda.gov.

[25] Willy H. Verheye. (2010) Soils Plant Growth and Crop Production - Volume I. 29-30. https://books.google.com.ly.